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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : H04R 17/00

A1

(11) International Publication Number: WO 97/42790

(43) International Publication Date: 13 November 1997 (13.11.97)

(21) International Application Number: PCT/US97/07845

(22) International Filing Date: 9 May 1997 (09.05.97)

(30) Priority Data:

08/644,843	9 May 1996 (09.05.96)	US
08/792,568	31 January 1997 (31.01.97)	US
60/038,961	24 February 1997 (24.02.97)	US
60/039,228	28 February 1997 (28.02.97)	US

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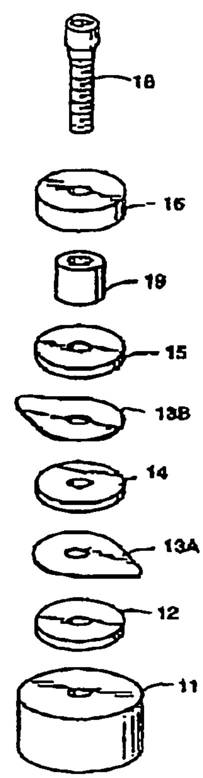
(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TR, TT, UA, UG, US, UZ, VN, ARIPO patent (GH, KE, LS, MW, SD, SZ, UG), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).

Published
With international search report.

(54) Title: ULTRASONIC TRANSDUCER

(57) Abstract

An ultrasonic transducer for generating and transmitting ultrasonic wave energy of a predetermined frequency to the surface of an object. In one embodiment, a resonator (12) is inserted between the head mass (11) and the piezoelectric crystal (14). The resonator is made from a material having an acoustic velocity equal to or greater than the object, preferably a ceramic such as a silicon carbide or alumina oxide. In another embodiment, the head mass (11) and tail mass (16) are also made from ceramic materials.



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ULTRASONIC TRANSDUCER

FIELD OF THE INVENTION

This invention relates to transducers which generate and transmit energy in the ultrasonic or megasonic ranges, and more particularly, to an transducer wherein ceramic materials, preferably silicon carbide or alumina oxide, are used as a resonator and/or substituted for metallic materials in such transducers.

BACKGROUND OF THE INVENTION

Ultrasonic transducers are used for generating and transmitting wave energy of a predetermined frequency to a liquid contained in a container. See, for example, U.S. Patent No. 3,575,383 entitled ULTRASONIC CLEANING SYSTEM, APPARATUS AND METHOD THEREFOR. Transducers of this type can be used, for example, in ultrasonic cleaning equipment. The transducer is typically mounted to the side or the underside of a container which holds liquid, or mounted in a sealed enclosure which is immersed in a liquid in a container made of metal, plastic or glass. A single transducer or a plurality of transducers are then used to energize the liquid with sonic energy. Once energized with the sonic energy, the liquid achieves cavitation.

This type of transducer is also referred to as a "sandwich"-type transducer because it has one or more crystals sandwiched between a head mass (or front driver) and the tail mass (or rear driver). A sandwich-type transducer is used in applications such as plastic welding, wire bonding, cataract and other medical surgical devices, among others.

A conventional transducer is illustrated in Figure 1 and includes a rectangular base 1, a pair of electrodes 2a and 2b, a piezoelectric crystal 3, an

insulator 4, a reflector 5, washers 6 and a bolt 7. However, when energized by a high frequency power source, the conventional transducer produces weak vibrations in the 20 to 100 kHz frequency range. The conventional transducer also evidences a tendency to shift in frequency by +/- 3 kHz due to various external factors. This shift requires periodically adjusting the frequency of the oscillatory circuit which energizes the transducers in order to match the shift.

One problem associated with out of phase oscillation is that it causes an increase in the temperature of the piezoelectric crystals. Since piezoelectric crystals cease to function when their temperature reaches the Curie point, there is the possibility of permanent degradation of the crystal.

Thus, the object of the present invention is to provide an enhanced ultrasonic transducer with superior acoustic performance which produces stable signals at predetermined frequencies.

SUMMARY OF THE INVENTION

The present invention is an enhanced ultrasonic transducer for generating and transmitting ultrasonic wave energy of a predetermined frequency to the surface of an object. In one embodiment, a resonator is inserted between the head mass and the piezoelectric crystal. The resonator is made from a material having an acoustic velocity equal to or greater than the object, preferably a ceramic such as silicon carbide or alumina oxide. In a preferred embodiment, the head mass and tail mass are also made from ceramic materials.

A better understanding of the features and advantages of the present invention will be gained by

reference to the following detailed description of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is an exploded perspective view of a conventional transducer.

Figure 2a is an exploded perspective view of one transducer embodiment according to the present invention.

Figure 2b is an exploded perspective view of another transducer embodiment according to the present invention.

Figure 3a is a graphical representation of the signal and impedance as a function of frequency generated by a prior art transducer having metal components.

Figure 3b is a graphical representation of the signal and impedance as a function of frequency generated by a transducer in accord with the present invention.

Figure 4a is a graphical representation of the signal and impedance as a function of frequency generated by a prior art transducer having metal components.

Figure 4b is a graphical representation of the signal and impedance as a function of frequency generated by a transducer in accord with the present invention.

Figure 5 is a schematic representation of a transducer assembly of the present invention used for ultrasonic welding for plastics assembly.

Figure 6 is a schematic representation of a transducer assembly of the present invention used for ultrasonic welding for wire bonding.

DETAILED DESCRIPTION OF THE INVENTION

One embodiment of an enhanced ultrasonic transducer according to the present invention is shown in Figure 2a. The transducer includes a base or head mass 11, a resonance enhancing disc or resonator 12, electrodes 13a and 13b, a piezoelectric crystal 14, an insulating member 15, a reflector or tail mass 16, washers 17, a bolt 18, and phenolic insert 19.

The head mass 11 is typically cylindrical and made of a suitable metal, such as aluminum or stainless steel. The head mass 11 is suitable for attachment to the surface of a container which holds liquid, such as a cleaning tank.

Coupled to the head mass 11 is a resonance enhancing disc or resonator 12. The resonator 12 can be made of material including, but not limited to, aluminum, ceramic, stainless steel or leaded steel. The resonator material should be adapted to readily transmit ultrasonic energy. More specifically, the resonator material will have transmission characteristics, such as acoustic velocity, which are greater or equal to the adjacent mass or object in order to gain the advantage of resonance enhancement. That is, the resonator must be located between the piezoelectric crystals and surface of the object that the sound will be transmitted through, and the resonator must have the same or higher acoustic transmission velocity than the object.

It is preferred that the resonator 12 be made from ceramic materials, and alumina oxide and silicon carbide are most preferred. The acoustic properties of ceramic, metal and other materials are already identified in the art and the appropriate selection of materials for use in the assemblies according to the present invention can readily be made by

referring to, for example, Selfridge, Approximate Material Properties in Isotropic Materials, ISEE Transactions on Sonics and Ultrasonics, Vo. SU-32, No. 3, May 1985, which is incorporated herein by reference.

The electrodes 13a and 13b are typically a conductive metal such as aluminum, brass or stainless steel.

The piezoelectric crystal 14 is typically made from lead zirconate titanate and, in one embodiment, ranges from 0.50 to 4.00 inches in diameter and 0.10-0.50 inches thick.

The insulator 15 is a common dielectric.

The metal reflector or tail mass 16 is typically cylindrical in shape and made of steel or leaded steel, like the head mass.

All of the components described above are assembled and coupled to the base mass 11 by tightening the bolt 18 to a torque pressure ranging from 150 inch-pounds for low power applications to 500 foot-pounds for high power applications. Optimally, the torque pressure is between 200 to 300 inch-pounds for low power applications (5 to 25 watts), and between 300 to 500 foot-pounds for high power applications (up to 3000 watts).

The thickness of the base 11, the resonator 12 and the reflector 16 are selected as an integral multiple of one quarter of the wavelength ($\lambda/4$) of the longitudinal sound vibrations in the medium.

The insertion of the resonator 12 in between the piezoelectric crystal 14 and the base 11 of the transducer increases the intensity of the resonant frequency signals by 30 to 40 percent. Further, the periodical shift in frequency is diminished, and the temperature of the piezoelectric crystals is stabilized.

The insertion of the resonator 12 also results in new resonant frequencies emerging in lieu of or in addition to the original resonant frequencies. For example, by inserting a 0.20 inch alumina ceramic resonator in the transducer stack, frequencies of 59 kHz, 101 kHz, 160 kHz emerged in lieu of 46 kHz, 122 kHz and 168 kHz. The substitution of resonators made from materials like stainless steel, aluminum and paramagnetic leaded steel produced similar results.

Thus, resonators made from both ceramics and metals increased the intensity of all the original resonant frequencies by about 30 to 60 percent, as measured by the decrease in the piezoelectric impedance (ohms) in the new transducer assemblies. This enhancement greatly increases the efficiency of an ultrasonic transducer and allows it to produce stable predetermined frequency signals.

When using conventional methods to go from a 40 kHz transducer to an 80 kHz transducer, the vertical and horizontal dimensions are halved, and the mass is reduced to one-quarter of the original size. This results in a corresponding reduction in the ability of the transducer to transmit sound waves. However, with the use of the present invention, a 40 kHz transducer can be modified to a 196 kHz transducer without any reduction in the vertical or horizontal dimensions of the crystal. In one test, we found that an enhanced 40 kHz crystal created more pressure at 122 kHz than at its original natural frequency of 40 kHz.

It should be noted that a resonance enhancing disc made of a polymeric material, specifically high density teflon, did not function to increase the intensity of the original resonant frequencies as did the discs made of metals and ceramics. Without being bound by a particular theory, it is believed that

materials such as high density teflon attenuate, rather than transmit, ultrasonic energy. Thus, those materials which will be useful as resonance enhancing disks would not encompass such attenuating materials, but would include any material which functions to increase the intensity of the original resonant frequencies.

By using a resonator made from a ceramic material which is selected to have sound transmission characteristics equal to or better than the adjacent mass (i.e. the transducer or other metallic or quartz substance that sound is transmitted through to perform its intended function), the following advantages are attained: (1) the clarity of the sound is enhanced; (2) the frequency can be raised to a higher resident frequency (as much as 500% higher); (3) the impedance level is lowered thereby improving the transmission of sound; and (4) the power generated by the piezoelectric crystal is the same as if the frequency had not been moved.

In a preferred embodiment of the invention, ceramic materials are substituted for metallic materials in a transducer stack thereby resulting in an enhanced device having superior acoustical performance, as will now be described in more detail.

Referring to Figure 2b, a transducer in accord with the present embodiment is similar to that illustrated in Figure 2a, except that the washers 17 are eliminated. The head mass and tail mass are made from a ceramic material, preferably silicon carbide or alumina oxide.

As previously discussed, it is advantageous to have resonator 12 in the stack, which may also be made from ceramic material such as alumina oxide or silicon carbide. However, it has been discovered that significant improvements in acoustical

performance are obtained merely by substituting ceramic materials for metals in the transducer stack. Thus, the inclusion of the resonator 12 is not required in this embodiment, although it is certainly recommended for maximum benefit.

It has been found that certain ceramic materials have adequate physical characteristics so as to be interchangeable with metals, but also possess superior acoustical properties. In building ultrasonic devices or transducers to transmit ultrasonic sound, it is therefore possible to substitute ceramic materials, such as aluminum oxide or silicon carbide, for metals (predominately stainless steel, aluminum and titanium) in the base 11 and in the reflector 16, resulting in superior acoustical properties which: (1) improves and enhances performance of existing frequencies; (2) makes it easier to find higher frequencies; and (3) allows the use of lower frequency PZT's to create higher frequencies with the same power as lower frequencies, which was previously impossible with all metal head and tail mass (or head mass only) designs.

Ceramics such as alumina oxide and silicon carbide can provide better flatness, and can meet or exceed the requirements for strength and durability of the metals and still yield improved acoustical performance, as shown by the relative acoustical properties of selected materials listed in Table 1:

TABLE 1

Material	Acoustical Index
<u>Metals</u>	
Aluminum	6.42
Stainless steel	5.79 1.1
Titanium	6.10 .989

<u>Ceramics</u>	
Aluminum oxide	10.52
Silicon carbide	13.06

Thus, for example, silicon carbide has a 2.034 superiority advantage over aluminum with aluminum being the best of the available metals being used today in most applications. This results from a calculation of 13.06 (silicon carbide index) ÷ 6.42 (aluminum index) = 2.034. For example, if a 0.2 inch resonator is made from silicon carbide, and inserted in the stack in place of one made from aluminum, the stack would require removal of 0.4068 inches of aluminum. Likewise, if you converted a 1 inch aluminum head mass in its entirety to silicon carbide, the height of the head mass becomes 1 ÷ (13.06 ÷ 6.42) = 0.4916 inches. The tail mass likewise is converted through the use of the appropriate acoustical index.

The entire transducer or transmitting device will show improvement if all parts are made from ceramics having superior acoustical properties than the metals they replace.

Silicon carbide is a superior ceramic for building all parts of transducers or devices to transmit ultrasonic sound. Silicon carbide is flatter, harder (except for diamonds), more durable and acoustically superior relative to other known metals or materials, or ceramics. Silicon carbide can be used as a resonator, head mass, tail mass, or vessel of transmission as follows: (1) as a resonating vessel to hold liquid that is being excited ultrasonically for cleaning, rinsing, degreasing, coating, processing and etc.; (2) as the transmitting device with ultrasonic liquid processors; (3) as the capillary or wedge used with

an ultrasonic wire or wedge bonding machine; (4) as a horn to receive the acoustical signals from a plastic assembly or welding machine converter mechanism; (5) as a triggering device to detonate a missile, torpedo, or other explosive device fired with ultrasonics; or (6) as a transmitter of sound for ultrasonic welding or bonding.

Silicon carbide is superior in acoustical properties to other ceramics used in wire-bonding and wedge bonding which get their energy from ultrasonics: (1) it is superior for capillary design based on its 13.06 acoustical index rating as compared with aluminum oxide (10.52); and (2) it is superior to tungsten carbide (11.0) as used for wedge bonding.

The performance improvement with substitution of ceramics for metals can be seen in Figures 3a and 3b, which illustrate an ultrasonic cleaning transducer involving 3,000 to 5,000 watts in a single group of transducers. Figure 2a illustrates the signal generated by a 68 kHz stacked transducer having metal components, while Figure 2b illustrates the signal generated by a 68 kHz stacked transducer having ceramic components. Note the sharp peak signal of the ceramic transducer stack as compared to the metal stack. Further, the impedance fell from 84.613 to 37.708 when ceramics were substituted for metals. Lower impedance is associated with better transmission of sound and greater efficiency.

Another example of the improvement obtained when ceramics are substituted for metals in low power transducer applications (10 to 15 watts) is shown in Figures 4a and 4b. Figure 4a shows the signal generated by a transducer stack having metal components, while Figure 4b shows the signal generated by a transducer stack having ceramic

components. It can be seen the ceramic stack pictured in Figure 3b produces two usable frequencies, namely 80 kHz with an impedance of 193 ohms, and 164 kHz with an impedance of 127 ohms.

In light of the foregoing, those familiar with transducers and ultrasonics generally will appreciate that the invention has applications in numerous areas, including but not limited to ultrasonic cleaning or precision cleaning, ultrasonic plastic assembly or plastic welding, ultrasonic friction welding, ultrasonic wire bonding (e.g. with gold or aluminum wire), ultrasonic wedge bonding, ultrasonic thermosonic bonding (ball bonding), non destructive ultrasonic testing equipment, ultrasonic cell disrupters (also known as liquid processors), ultrasonic emulsifiers, megasonic ultrasonics for frequencies from 200 - 1200 kHz, medical ultrasonics, and nebulizers.

Other possible applications include:

Military: hydrophones, depth sounders, fuse devices, level indicators, pingers, missile launchers, missile, sonobuoys, targets, telephony, subsurface bottom profiling, ring laser gyros, torpedo launchers, torpedo.

Automotive: knock sensors, radio filters, tread wear indicators, fuel atomization, spark ignition, keyless door entry, wheel balancers, seat belt, buzzers, air flow and tire pressure indicators, audible alarms.

Commercial: ultrasonic aqueous, cleaners, ultrasonic semi-aqueous cleaners, ultrasonic wire bonding, ultrasonic wedge bonding, thickness gauging, level indicators, geophones, tv and radio resonators, ignition systems, relays, non destructive material testing, liquid processors, ultrasonic plastic welders, ultrasonic sewing machine, ultrasonic

degreasers, flaw detection, flow meters, ultrasonic drilling, delay lines, airplane beacon locators, fans, ink printing, alarm systems.

Medical: micro brain surgery, ultrasonic cataract, removal, insulin pumps, flow meters, ultras onic imaging, vaporizers, liquid processors, ultrasonic scalpels, ultrasonic therapy, fetal heart detectors, nebulizers, disposable patient monitors, ultrasonic dental devices, cell disrupters.

Consumer: humidifiers, telephone devices, microw ave ovens, phonograph cartridges, cigarette lighters, musical instruments, fish finders, gas grill igniters, smoke detectors, jewelry cleaners, speakers, security lighting, ultrasonic sewing.

Referring now to Figures 5 and 6, other embodiments of the invention will be described.

Figure 5 shows an arrangement which includes a transducer stack 30 for use in ultrasonic plastic welding. In this stack, there is a ceramic tail mass or back driver 31, piezoelectric crystals 32a and 32b, an aluminum electrode 33 positioned between the crystals, a ceramic resonator 34 and a ceramic head mass or front driver 35. For this use, the transducer 30 is connected to a welding horn 36 by bolt 37 such that the head mass 35 is in contact with the welding horn. The welding horn 36 interfaces with the parts being ultrasonically bonded. This device is also generally known as a converter, and can handle high power plastic welding requirements up to 3000 watts.

Figure 6 shows a transducer stack 40 for use in wire bonding. In this stack, there is a ceramic tail mass or back driver 41, piezoelectric crystals 42a, 42b and 42c, interlocking brass electrodes 43a and 43b, a ceramic resonator 44 and a ceramic head mass or front driver 45. For this use, the transducer 40

is connected to a horn 48 by screw or bolt 47 in the same manner as the previous embodiment such that the head mass 45 is in contact with the horn. This device is also generally known as a motor for wire bonding, and can handle low power bonding requirements of approximately 10 to 15 watts.

In most instances, it may be advantageous to have a ceramic resonator and an intervening ceramic mass rather than have a single ceramic mass.

It may also be possible to remove the head mass altogether and have direct bonding between either the crystal or the resonator and the surface of interest.

In summary, this invention relates to an improved ultrasonic transducer for generating and transmitting ultrasonic wave energy of a predetermined frequency. The improvement resides in the use of a resonator and/or the substitution of ceramic material, preferably silicon carbide or alumina oxide, for metal components in a transducer stack.

Once those skilled in the art understand the advantages of substituting ceramic materials for metals as disclosed herein, the required thicknesses for elements in a transducer stack may be readily identified for optimal performance, and the specific geometries required for specific applications can be readily determined.

It should be understood, however, that the invention is not intended to be limited by the specifics of the above-described embodiments, but rather defined by the accompanying claims.

We claim:

1. An apparatus for generating and transmitting ultrasonic energy to an object, comprising first and second electrodes positioned on opposite sides of piezoelectric material, the improvement comprising positioning a resonator adjacent one of the electrodes which electrode is positioned between the piezoelectric material and the object, wherein the resonator is made from a material having an acoustic velocity equal to or greater than the object.

2. The apparatus of claim 1 wherein the resonator is made from a ceramic material.

3. The apparatus of claim 2 wherein the ceramic material is silicon carbide or alumina oxide.

4. The apparatus of claim 1 wherein the object is made from the same material as the resonator.

5. An ultrasonic transducer stack for generating and transmitting sonic energy to a surface of interest, comprising:

a piezoelectric crystal,

a head mass made from ceramic material and coupled between the piezoelectric crystal and the surface of interest, and

a tail mass made from ceramic material and coupled to the piezoelectric crystal opposite the head mass.

6. An ultrasonic transducer as in claim 5, further comprising a resonator made from ceramic

material and positioned between the head mass and the piezoelectric crystal.

7. An ultrasonic transducer as in claim 5, further comprising an insulator made from ceramic material and positioned between the tail mass and the piezoelectric crystal.

8. A transducer stack as in claim 5, wherein the ceramic material is silicon carbide or alumina oxide.

9. A transducer stack as in claim 6, wherein the ceramic material is silicon carbide or alumina oxide.

10. A transducer stack as in claim 7, wherein the ceramic material is silicon carbide or alumina oxide.

11. A transducer stack as in claim 5, further comprising a first electrode positioned between the head mass and the piezoelectric crystal and a second electrode positioned between the tail mass and the piezoelectric crystal.

12. An ultrasonic transducer stack for generating and transmitting sonic energy to a surface of interest, comprising:

a head mass made from ceramic material and coupled to the surface of interest,

a tail mass made from ceramic material,

at least two piezoelectric crystals positioned between the head mass and the tail mass, and

an electrode positioned between the at least two piezoelectric crystals.

13. An ultrasonic transducer as in claim 12, further comprising a resonator made from ceramic material and positioned between the head mass and one of the piezoelectric crystals.

14. A transducer stack as in claim 12, wherein the ceramic material is silicon carbide or alumina oxide.

15. A transducer stack as in claim 13, wherein the ceramic material is silicon carbide or alumina oxide.

16. An ultrasonic transducer stack for generating and transmitting sonic energy to a surface of interest, comprising:

a head mass made from ceramic material and coupled to the surface of interest,

a tail mass made from ceramic material,

a plurality of piezoelectric crystals positioned between the head mass and the tail mass, and

an electrode positioned between at least two of the piezoelectric crystals.

17. An ultrasonic transducer as in claim 11, further comprising a resonator made from ceramic material and positioned between the head mass and the piezoelectric crystals.

18. A transducer stack as in claim 11, wherein the ceramic material is silicon carbide or alumina oxide.

19. A transducer stack as in claim 12, wherein the ceramic material is silicon carbide or alumina oxide.

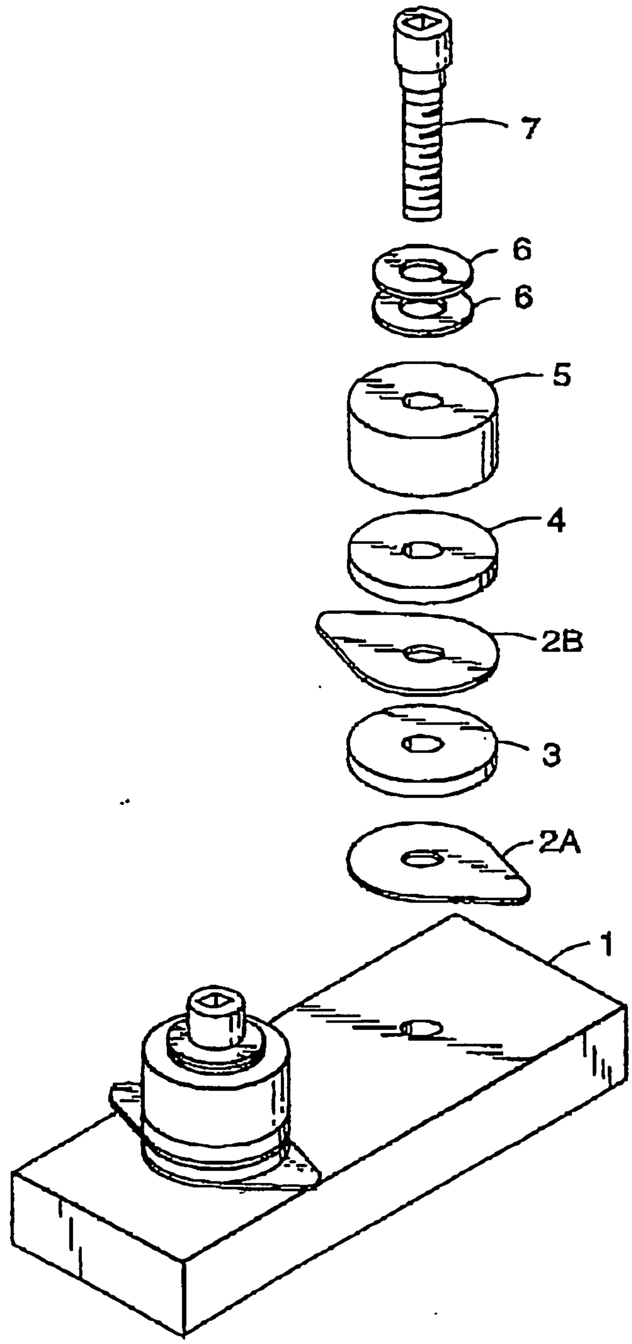

FIG. 1

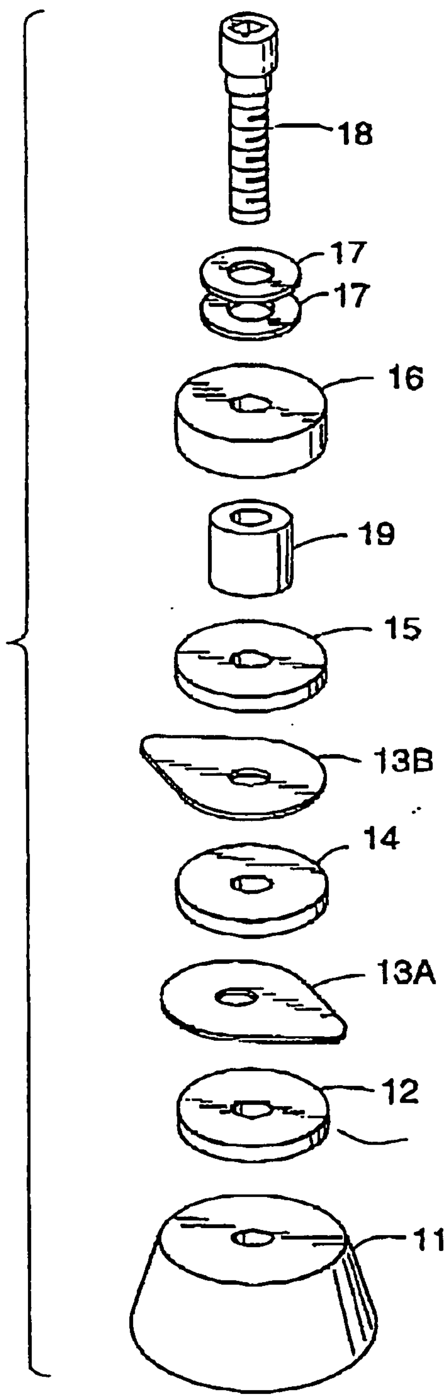

FIG. 2A

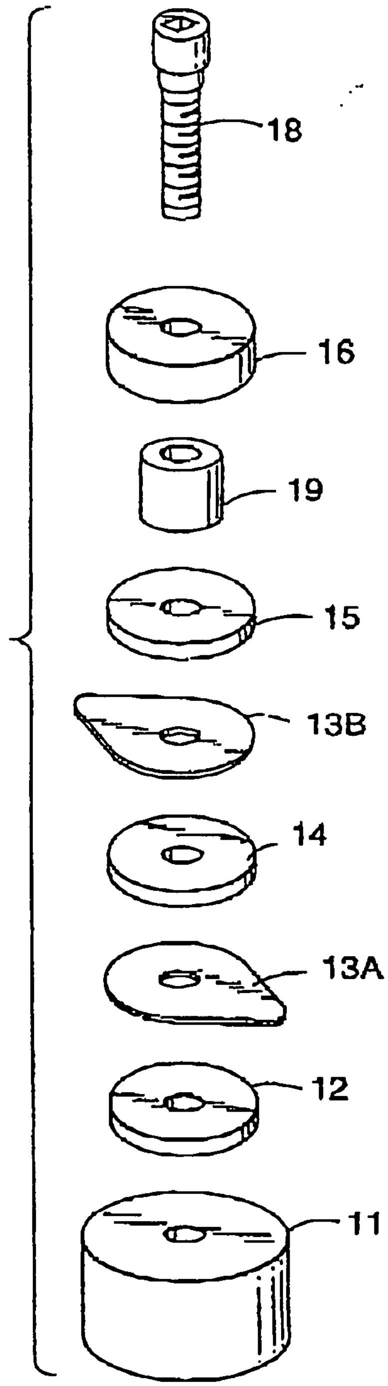

FIG. 2B

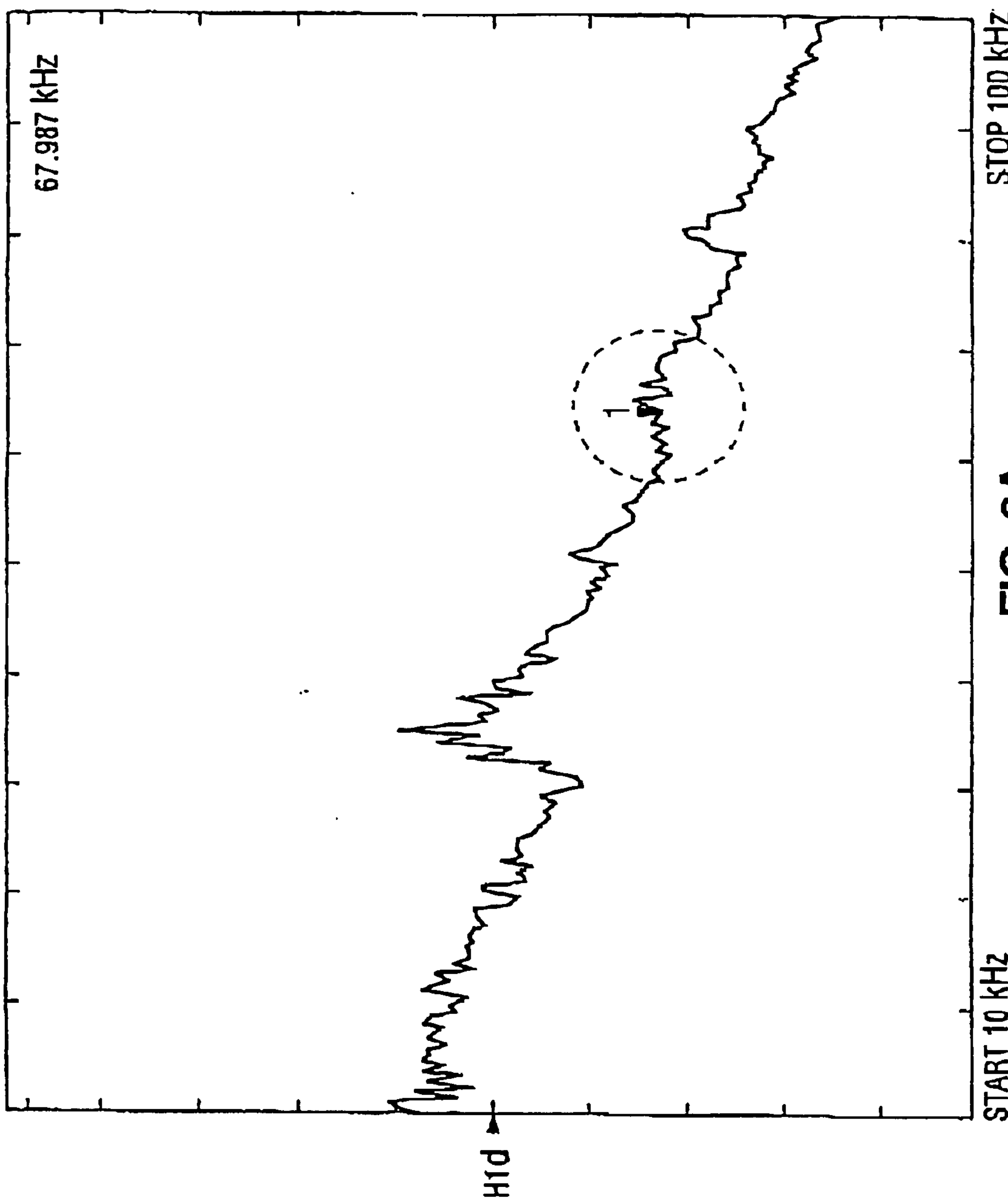

FIG. 3A

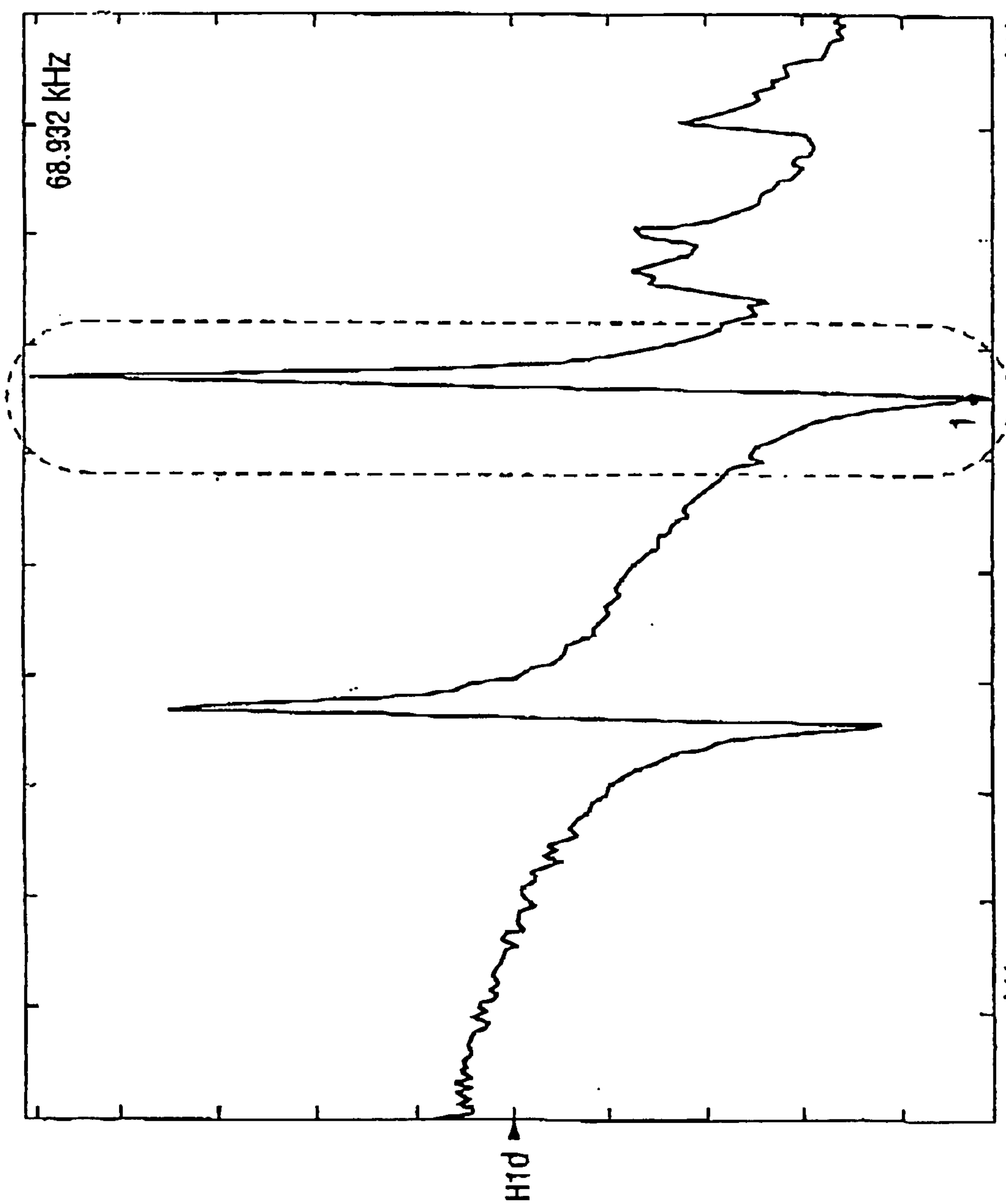

FIG. 3B

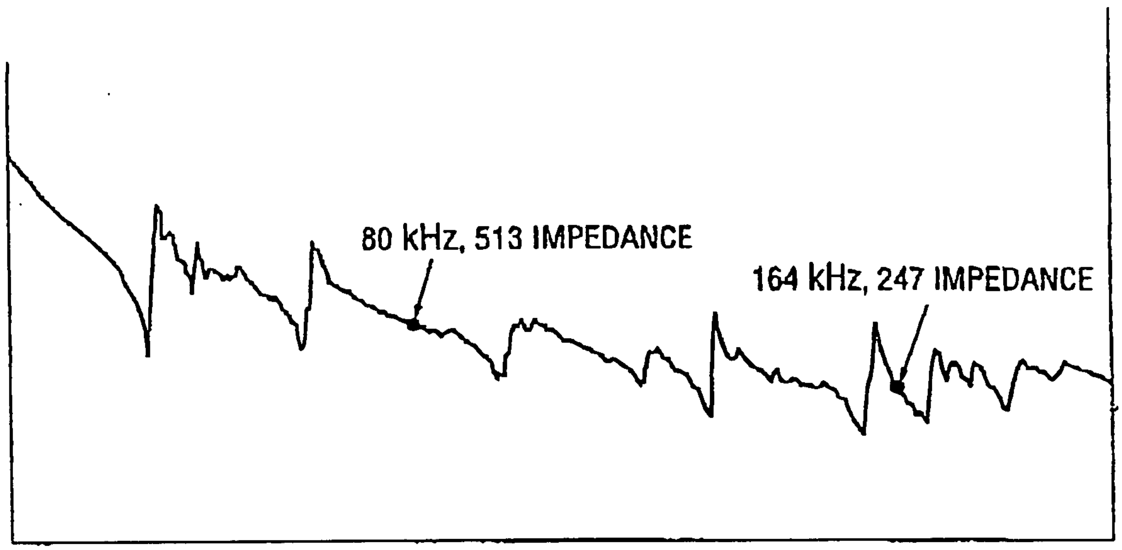
80 kHz, 513 IMPEDANCE
164 kHz, 247 IMPEDANCE

FIG. 4A

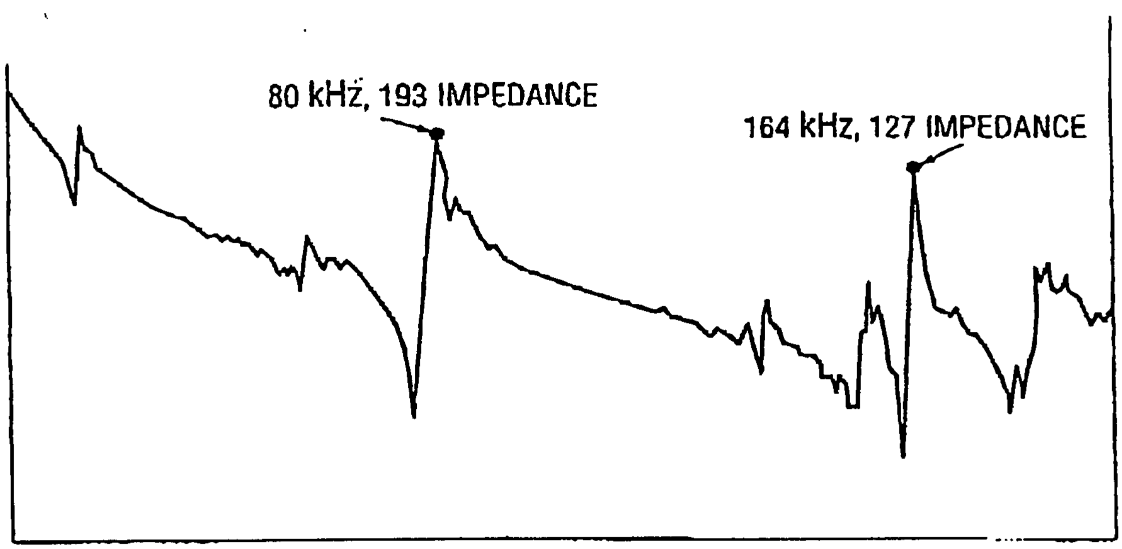
80 kHz, 193 IMPEDANCE
164 kHz, 127 IMPEDANCE

FIG. 4B

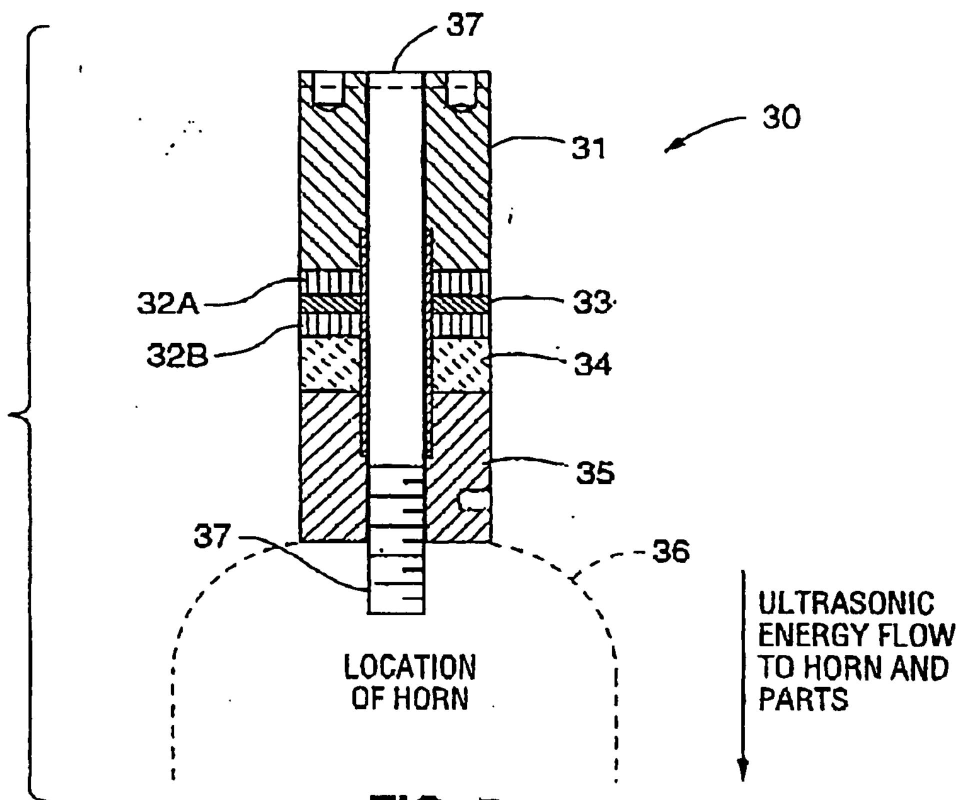
37
30
31
32A
33
32B
34
35
37
36
LOCATION OF HORN
ULTRASONIC ENERGY FLOW TO HORN AND PARTS

FIG. 5

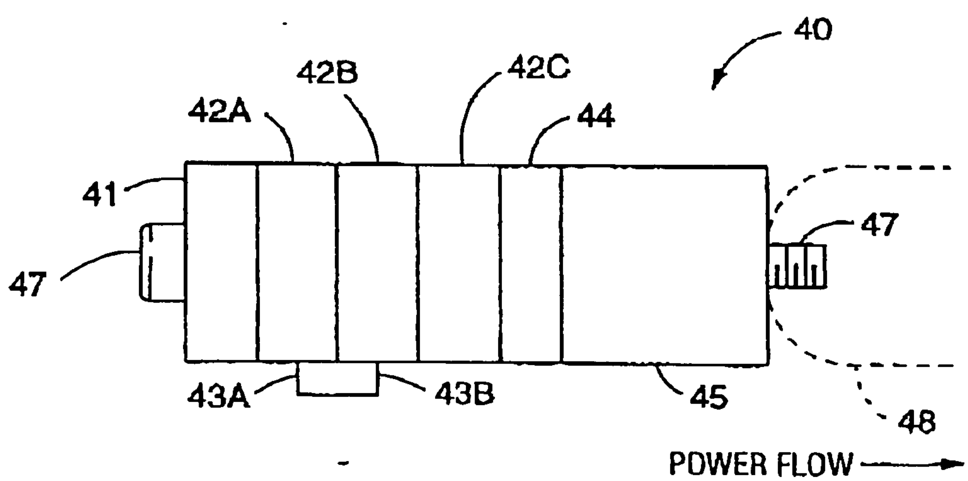
40
42B
42C
42A
44
41
47
47
43A
43B
45
48
POWER FLOW

FIG. 6